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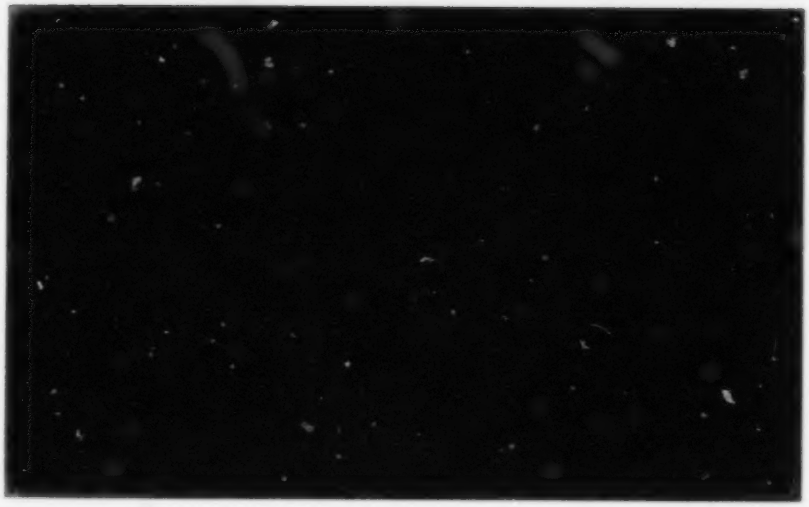

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Improving Intercity Freight Routing with a Tactical Planning Model

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ABSTRACT

Routing decisions play an important role in the planning and management of operations of LTL motor-carriers. They strongly interact with service and terminal operation policy choices, and are particularly sensitive to variations in demand. In this paper, we present results from several experimental studies conducted with large Canadian carriers, by using a network optimization based methodology for tactical planning of freight transportation that we developed. These results illustrate the complexity of the routing decisions, and the importance of tactical analysis and planning for the efficiency of intercity freight transportation.

Keywords: Intercity freight transportation, routing decisions, tactical planning, less-than-truckload motor carrier transportation.

RÉSUMÉ

Les décisions relatives aux routes utilisées pour le transport des marchandises jouent un rôle vital pour la planification et la gestion des opérations des entreprises de camionnage de charges partielles. Ces décisions interagissent fortement avec celles concernant l'établissement des normes de service et des politiques d'opération des terminus. De plus, elles sont sensibles aux variations de la demande. Nous présentons dans cet article des résultats de plusieurs analyses, effectuées à partir des cas de grands transporteurs canadiens, à l'aide d'une méthodologie pour la planification tactique des opérations de transport de marchandises que nous avons mis au point. Ces résultats illustrent à la fois la complexité des décisions relatives aux routes de fret et l'importance de l'analyse et de la planification tactique pour l'efficacité du transport interurbain de marchandises.

Mots-clés: Transport interurbain de marchandises, établissement de routes de fret, planification tactique, camionnage de charges partielles.

I INTRODUCTION

The current deregulation trend of the North American transportation industry places the intercity freight motor-carrier in a highly competitive environment where only rapid and precise adjustments of prices and services to external factors will allow it to survive and prosper. Consequently, a most valuable asset for the company is the capability for efficient generation and analysis of good operating strategies that satisfy not only traditional cost minimization criteria but also somewhat conflicting service quality criteria.

We have developed a network optimization model aimed at assisting motor carriers attain these objectives. It integrates the many facets of the decision-making process at the tactical level of planning, such as the design of the transportation service network and the routing of freight; it describes their relationships and network-wide influence.

The routing aspect of the problem presents a particularly difficult challenge, since routing decisions not only strongly interact with service and terminal policy choices, but are also sensitive to variations in demand, both globally and at the market scale. Thus, contingency planning with respect to demand is an essential part of tactical planning. Our model is particularly well adapted to this function.

In this paper, we present results from several experimental studies conducted with large Canadian carriers. Our objective is to illustrate the complexity of the routing decision and the importance of tactical analysis and planning. We also demonstrate the excellent performance of our model, both in terms of efficiency and in terms of the quality of its solutions. We first briefly describe how motor carriers generally operate and present some of the associated planning issues. We then describe the load planning problem and briefly review existing planning models that can be used at the

tactical decision level. The next section describes the model. This is followed by an extensive description of various studies and analyses performed using our model. Finally, we conclude with an overview of new and future developments related to freight routing issues involving our model.

II THE NATURE OF PLANNING IN THE MOTOR CARRIER INDUSTRY

2.1 Motor carrier operations

Intercity trucking companies are generally specialized in the transportation of one of the following type of shipments:

1) truckload (TL) freight;
2) less-than-truckload (LTL) freight;
3) parcels.

TL freight transportation is characterized by individual shipments which require an entire trailer - i.e. one per shipment. Thus, freight does not require service routing decisions, nor sorting and handling as it moves directly from shipper to consignee. As a result, investment in terminals and in specialized city pickup and delivery equipment is not necessary in this case (Barker, Sharon and Sen, 1981).

An LTL carrier typically hauls shipments in the range of 100 to 10,000 pounds - 50 to 4500 kg (Powell and Sheffi, 1983). Since a trailer can hold 30,000 to 50,000 pounds depending on the density of freight, it is necessary for the carrier to consolidate many shipments to make economic use of the vehicle. This requires the establishment of a large number of terminals to sort freight. These terminals may be either end-of-line terminals, which correspond to points of origin and destination of freight and which have to maintain a fleet of small trucks for handling pickups and deliveries in the city, or breakbulk terminals which perform only the consolidation of freight. In Canada the same terminal usually performs both functions.

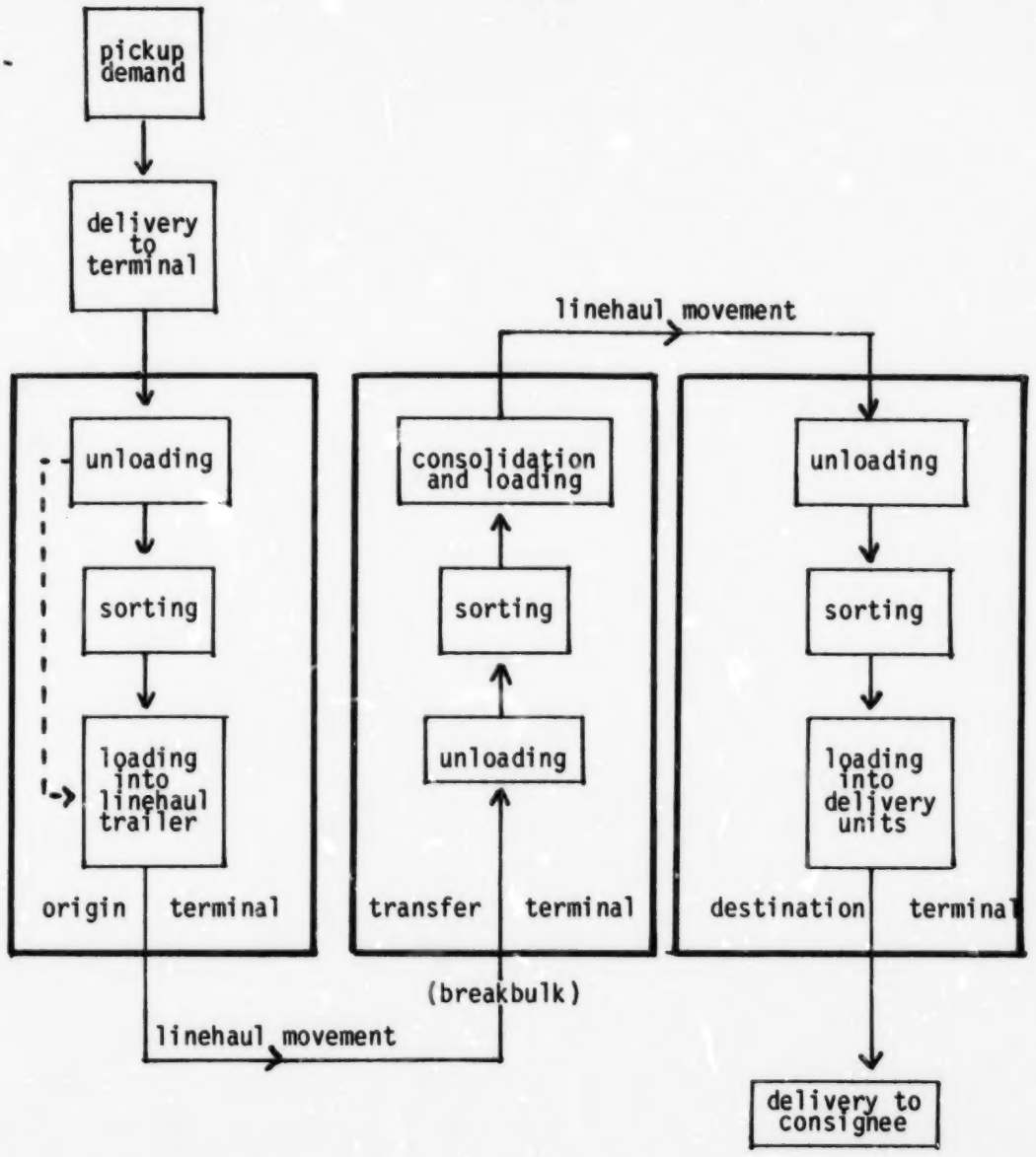


Figure 1 : A typical LTL shipment has to go through several terminals where a number of consecutive labor-intensive operations (unloading, sorting, consolidating, loading) will be performed. Conversely, TL shipments will skip all terminal operations.

For a better understanding of the LTL carrier's operations, Figure 1 represents the typical flow of shipments (Wyckoff, 1974). The cycle starts with a pickup demand which is seldom known in advance and may vary significantly from one day to another. Demand for transportation services also varies according to seasonal variations and type of traffic. For example, early spring and fall are peak periods in the garment industry. Shipments are generally collected in the afternoon and then delivered to the origin terminal where they are unloaded and verified against the information appearing on the documentation (bill of loading) prepared by the shipper: weight, dimensions, number of pieces per shipment, type of traffic, etc. Tariffs are determined and a waybill is prepared. The waybill is the documentation that accompanies the traffic and is used to verify it in subsequent handling operations. Once unloaded and verified, freight is loaded into a linehaul trailer and moved to the nearest breakbulk terminal if the origin terminal does not perform the sorting function. Otherwise, freight is sorted according to its immediate destination and then moved to its loading area where it awaits loading into linehaul trailers. Traffic addressed to other points in the origin city is directed to loading zones for local delivery (normally the next morning).

As mentioned earlier, it is not always possible to economically dispatch a trailer for each destination where traffic is addressed. Freight is then consolidated into trailers for an intermediate terminal where it will be loaded with other traffic for movement to its final destination. In fact, traffic may once again be unloaded, sorted and reloaded at the transfer terminal. It is sometimes possible to keep this traffic in the "nose" of the trailer and add some more traffic to it, in which case the handling costs are considerably reduced. Several such intermediate terminals may be required for low volume long distance shipments. Thus,

decisions concerning the routing of freight through the terminal and service network acquire a prime role in the carrier's planning process.

At the destination terminal, traffic will once again be unloaded, verified, sorted, coded and moved to a loading area for local delivery to its consignee. Note that linehaul movements occur mostly during the night, so that freight can be delivered to consignees in the morning (Roy and Picard, 1984; Roy, 1984).

Carriers specialized in the transportation of parcels (small shipments of less than 50 pounds), such as UPS in the United States and Canada Post Corporation, have many characteristics in common with an LTL carrier. More particularly, they must also consolidate shipments; their terminal network is thus in some ways very similar to that of an LTL carrier.

2.2 Levels of planning

Motor carriers' operations management problems can generally be classified according to the following three levels of planning: strategic, tactical and operational.

Decisions taken at the strategic planning level usually concern a large part of the organization, have major financial impacts and may have long term effects. In the motor-carrier industry, these decisions are typically related to the design of the transportation system (Roy and Picard, 1984), that is, to:

1) the type and mix of transportation services offered (parcels, TL or LTL services);
2) territory coverage and network configuration including terminal location;

3) the service policy definition, i.e. the service levels offered to customers in terms of both speed and reliability.

At any point in time, these decisions will help determine the motor-carrier's strategic position in the market. These strategic choices should therefore be revised periodically following changes that are continually taking place in the motor-carrier's particular environment.

Needless to say that the trucking industry's deregulation movement initiated in the United States with the Motor-Carrier Act of 1980 and the new framework provided by the Free Trade Agreement between the U.S.A. and Canada, should enhance the carriers' interest for strategic planning models which can be used as decision aids in a more competitive and uncertain environment. In any case, choices made at the strategic level will constrain the decision variables at the tactical and operational levels.

The tactical planning level is located somewhere between long-range strategic planning and day-to-day operations planning. It is thus related to short or medium range activities such as:

1) equipment acquisition or replacement;
2) capacity adjustments according to demand forecasts and the financial situation of the firm;
3) service network design, freight consolidation and routing decisions (load plan).

In the motor-carrier industry, tactical planning may be performed over a time horizon of a few years, such as in the case of vehicle replacement or freight handling equipment purchases, or over a period of a few months when, for example, adjusting the transportation (load) plan according to seasonal variations in the forecasted demand.

Tactical planning will generally influence decisions made at the operational level, that is decisions concerning very short term day-to-day operations or even real-time management. At the operational level, carriers are mostly concerned with detailed planning of current activities, and decisions are often made at the first line supervisory levels. Starting with transportation plans formulated at the tactical level, motor-carriers have to decide for example on driver and equipment assignments and transportation schedules that have to be updated according to daily variations in demand as well as equipment and labor availability. Finally, in real time management, operational planning and control are performed together in order to maintain the transportation system under equilibrium.

The hierarchical, or vertical, relations amongst the three planning levels greatly contributes to the impracticality of formulating a unique model; it generates the need for different formulations addressing specific planning levels or problems (Crainic and Roy, 1987). At each planning level, and particularly so at the tactical level, a second type of relation, called horizontal, can also be observed amongst the various decisions. In fact, strategies developed for one problem interact with those established for other problems, and require that decisions be made globally, network-wide, in an integrated manner (Crainic and Roy, 1987). We return to this issue in the next section.

III THE LOAD PLANNING PROBLEM

One of the main tactical problems facing LTL carriers is, without any doubt, the determination of the transportation - or load - plan for the coming months. Powell (1986) defines this problem as the specification of how freight should be routed (and consolidated) over the network, given a set of direct services between terminals. This routing is done by

minimizing transportation and handling costs while improving - or at least maintaining - preset service objectives. A load plan must consider the three following interrelated subproblems:

1) service network design, i.e. the selection of routes on which carrier services will be offered and the determination of the characteristics of each service such as its mode, speed and frequency (number of vehicle departures on a given route per planning period);
2) traffic routing, i.e. for each origin-destination pair (or market) with a positive traffic demand, which sequence of services will be used to move freight and which consolidation terminals will be used;
3) empty vehicle movements, i.e. the determination of empty movements required to establish the balance between the number of vehicles departing and those arriving at each originating terminal in the network.

The construction of a good load plan is a complex task, as illustrated in the following example. Let us suppose that the demand for LTL transportation for a given market pair is expected to increase in the coming months. We then could increase the number of trailer departures at the origin terminal, and possibly at intermediate terminals, in order to satisfy this additional demand; such a policy would increase transportation costs while maintaining present service speed and reliability levels. We could also decide to maintain the existing number of movements, and forward the additional freight through other intermediate terminals in order to maximize the utilization of trailer equipment. However, this second policy would increase freight handling costs, total transit time and terminal

congestion which, in turn, could affect service reliability. These strong ties among the various aspects of the problem, and the inherent trade-offs between service and costs, illustrate the large number of possible operating strategies and the complexity of the decision process and justify the use of integrated optimization-based planning models.

Delorme, Roy and Rousseau (1988) present a thorough review of the available models for assisting motor carrier companies with their various planning tasks. The authors found only two modeling efforts that attempted the global optimization of the load planning problem.

Powell and Sheffi (1983) proposed a network optimization model to solve the problem. Their model was later extended and the solution method improved (Powell, 1986). It was then installed as an interactive computer package at a large U.S. LTL firm (Powell and Sheffi, 1986).

The formulation yields a large mixed integer programming problem which takes into account the design of the service network as well as the traffic routing and empty balancing process. The optimal load plan is obtained by minimizing the total linehaul and handling cost while ensuring that satisfactory levels of service are provided. The solution algorithm is based on a local improvement heuristic which drops and adds links (i.e. services) to a given initial network using a specific sequencing logic. After each modification, flow is rerouted using a decomposition method and an adaptation of a shortest path algorithm. Numerical experiments carried out by Powell (1986) on a network composed of 12 breakbulk and 128 end-of-line terminals suggest that the solution method works efficiently. One of the main features of the system is its ability to deal with unprogrammable decision rules regarding the service network design: the planner may decide in an interactive manner where direct services should be offered, given suggestions provided by the model.

Despite the apparent success of their model for solving the load planning problem, several aspects of intercity freight transportation systems were not considered by Powell and Sheffi. In particular, service frequencies are not explicit decision variables in the model; they are more an output of it as they are estimated from the total flow (in trailerloads) carried on each link of the service network. Moreover, the variable flows are not restricted to take integer values only. In addition, the model ignores congestion phenomena which happen at breakbulk terminals when, for instance, the volume to be sorted or the number of trucks to be unloaded increases. Finally, service characteristics such as the transit time of freight and its variability are not considered in the model. According to the authors, these simplifications were necessary because of the size and the nature of the problem. Indeed, national carriers in the U.S.A. typically operate a network of 300 or more terminals including those dedicated exclusively to breakbulk functions.

Recently, Crainic and Rousseau (1985) have proposed a general modeling framework for the medium-term planning problem of multimode, multicommodity freight transportation systems which takes into account the above-mentioned elements missing from Powell and Sheffi's model. It was first used to solve a complex rail application (Crainic, Ferland and Rousseau, 1984, Crainic, 1988) and later adapted by Roy (1984) for LTL problems. An overview of the methodology, as well as the general design of the planning tool currently under development, are presented by Crainic and Roy (1987). The structure of the LTL model, named NETPLAN ("NETwork PLANning") is presented in the next section.

IV THE MODEL

NETPLAN is intended to assist motor-carriers in their decision-making process concerning the design of the service network, the routing of freight and the empty vehicles balancing problem. It is formulated (Roy and Delorme, 1989) as a non-linear mixed integer programming problem, where service frequencies as well as the volume of freight moving on each route (or itinerary) through the network are the main decision variables. Their values are determined by minimizing a total system cost (defined below) while satisfying the demand for transportation, specified for each market, and integrality constraints on frequencies; decision variables are required to be nonnegative. The trade-offs to be made between operating costs and both speed and reliability of service are explicitly considered by NETPLAN at the objective function level. Thus, the main function of NETPLAN is to propose a solution that provides the required service at minimum cost.

The total system cost is the sum of:

1) intercity transportation costs, which may vary according to the type of services used and their frequencies;
2) freight consolidation costs, which depend on the amount of freight handled at breakbulk terminals;
3) capacity penalty costs, which penalize the over-utilization of trailer capacity for each transportation service;
4) service penalty costs, which are incurred when service performance standards are not met, considering both the mean and variance of planned transit times for each market.

Service penalty costs are modeled by estimating the delays which occur at terminals and over the road. These delays fall into one of the following four categories:

1) the intercity transportation time for each service. This is usually estimated from historical data;

2) the waiting time of vehicles at each terminal before unloading. This delay depends on the size and configuration of the terminal as well as on the productivity of the employees assigned to handling operations. Its estimation is based on queuing theory;

3) the time incurred to unload and sort freight at each terminal. This is expressed as a function of the average volume of freight carried by a vehicle (determined by NETPLAN) and of the unloading rate at the terminal in volume units per hour;

4) the frequency delay for each service, i.e. the time spent by freight at loading docks waiting for the next vehicle departure. This delay, which is obtained from queuing analysis methods, depends on the service capacity as well as on its utilization rate.

The transit time for a given itinerary is computed by adding up the frequency delays and the transportation times related to each service used, as well as all the delays incurred at each terminal encountered. For a more detailed description of all these terms, see the work by Roy (1984).

Other types of constraints, such as restrictions on the utilization of given types of vehicles, may be easily added to the model through the use of penalty costs at the objective function level. NETPLAN can also take into account other specific operations of LTL carriers, like for instance the transportation of baseloads when the LTL volume on a given link of the

service network is insufficient to justify the regular use of vehicles in order to maintain high service standards. (A baseload is a shipment which takes up about half a trailer capacity and which always remains in the "nose" of the trailer — the unused space may be filled up with LTL shipments — and it is considered as a TL shipment; it is therefore never handled at terminals.) Note, finally, that the model may be extended to handle several types of products for the planning of the activities of carriers specialized in the transportation of parcels.

One of the main characteristics of NETPLAN's formulation is its large size. To solve this kind of problem, Crainic (1982) has developed an algorithm based on a decomposition scheme, which makes use of the problem's special structure. The solution method is detailed in Crainic and Rousseau (1985).

V EXPERIMENTATION

Our tactical planning model has been tested on real data provided by two Canadian LTL trucking companies : CN Express (CNX), a division of Canadian National which, at the time, operated across Canada, and Transport Brazeau Inc., which served markets from Vancouver to Quebec City. Table 1 summarizes the characteristics of the two data sets. Extensive experimentation has been conducted on this data on a CDC Cyber 173 computer. Experimental results are reported in Roy and Delorme (1989) along with various analyses that illustrate the usefulness of our model in better understanding overall cost/service trade-offs. We now present some additional results that show how the routing of LTL freight can be improved with the use of our tactical planning model by studying possible variations in demand, transportation services and network configuration.

COMPANY	CN EXPRESS INC.	TRANSPORT BRAZEAU INC.
Year of the test data	1982	1985
#of terminals	34	35
#of markets	959	453
#of operated services	289	259

Table 1 : The analyses presented in this paper were performed on data provided by two large Canadian LTL trucking companies.

5.1 Demand Variations - Global Demand

When varying the demand level, d_m, by ± 20% for all markets m, we found that only a relatively small number of itineraries were modified for the most important markets, i.e. those 288 markets representing approximately 92% of all demand, in the CNX tests. But when itineraries are modified, it is possible to further study these modifications in order to determine contingency plans (itineraries) that can be implemented when required. The following examples provide illustrations of how the routing of freight should be modified according to changes in overall demand levels.

Case # 1 : The Halifax to Toronto market

Figure 2 shows how freight should be routed from Halifax to Toronto depending on the general demand level, d_m.

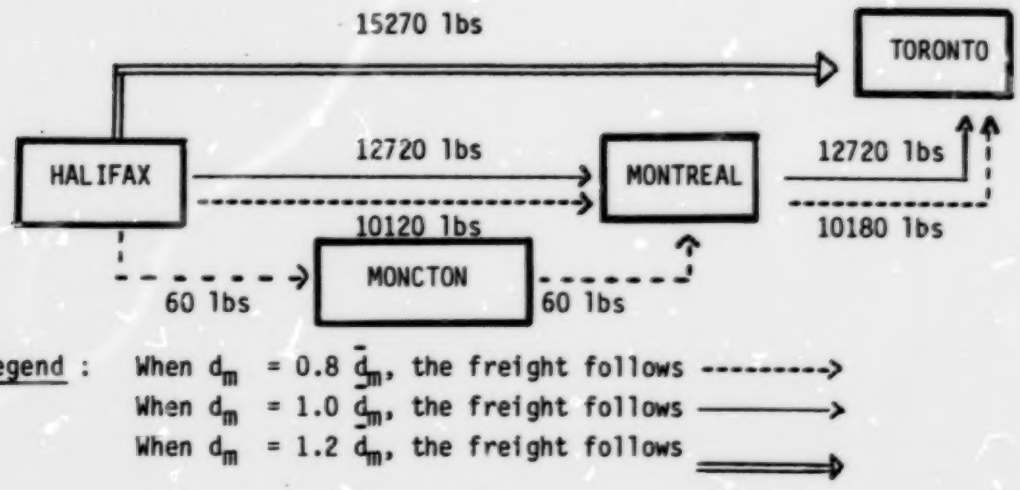
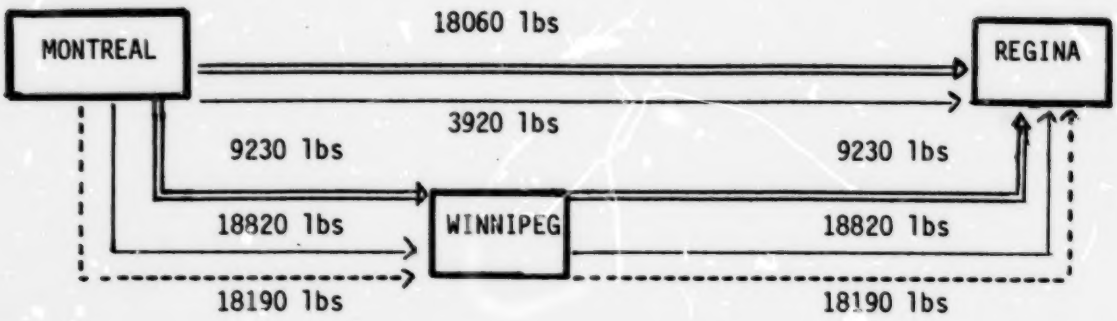


Figure 2 : NETPLAN can provide assistance to motor carriers in determining the best routing of freight for varying demand levels. Here, freight must be routed through Montreal for consolidation purposes as long as the general demand level is not sufficient to economically justify a direct link between Halifax and Toronto.

When using the actual demand ($\bar{d}_m$) of 12 720 lbs per week, the model suggests that freight be routed through Montreal for consolidation purposes. When demand is decreased by 20% (d_m = 0.8 $\bar{d}_m$), we find that a small portion of freight, i.e. 60 lbs, must be routed through Moncton due to a lack of capacity on the transportation service between Halifax and Montreal. In this case, the model has determined that it is more economical to pick-up additional handling and service penalty costs for those 60 lbs, rather than to add one more trailer between Halifax and Montreal. Finally, a 20% (d_m = 1.2 $\bar{d}_m$) increase in demand is sufficient to economically justify a direct service between Halifax and Toronto.

Case # 2 : The Montreal to Regina Market

Figure 3 indicates how freight should be routed between Montreal and Regina according to various demand levels.



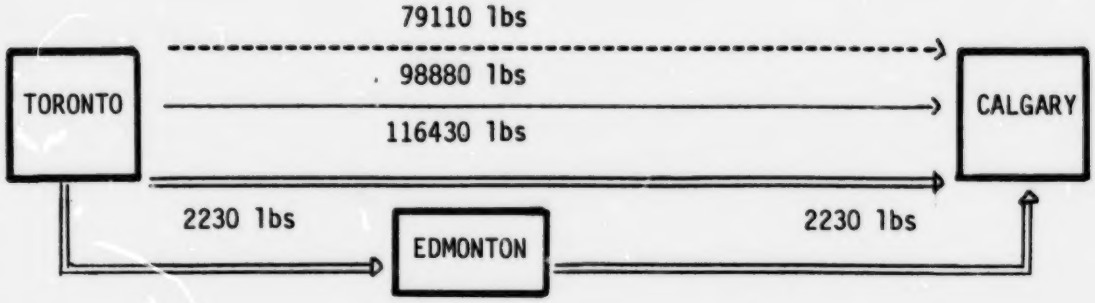
Legend : When $d_m = 0.8\ \bar{d}_m$, the freight follows ---------→
When $d_m = 1.0\ \bar{d}_m$, the freight follows ——————→
When $d_m = 1.2\ \bar{d}_m$, the freight follows ═══════→

Figure 3 : In this case, as the general level of demand increases, the model calls for a larger portion of the freight to use the direct transportation link between Montreal and Regina.

With the actual demand ($\bar{d}_m$) of 22 740 lbs per week, most of the freight, i.e. 18 820 lbs, is routed through Winnipeg and only 3 920 lbs are sent directly from Montreal to Regina. When demand is decreased by 20% ($d_m = 0.8\ \bar{d}_m$), all the freight is consolidated at Winnipeg and when demand is increased by 20% ($d_m = 1.2\ \bar{d}_m$), the majority of freight is moved directly from Montreal to Regina. In this case, the model establishes trade-offs between increased handling costs when traffic is routed through Winnipeg, and service penalty costs, when using the direct link incurred, because the corresponding Montreal to Regina service frequency is not set high enough to fully satisfy the market service requirements.

Case # 3 : The Toronto to Calgary Market

Figure 4 shows how freight is routed between Toronto and Calgary for varying demand levels.



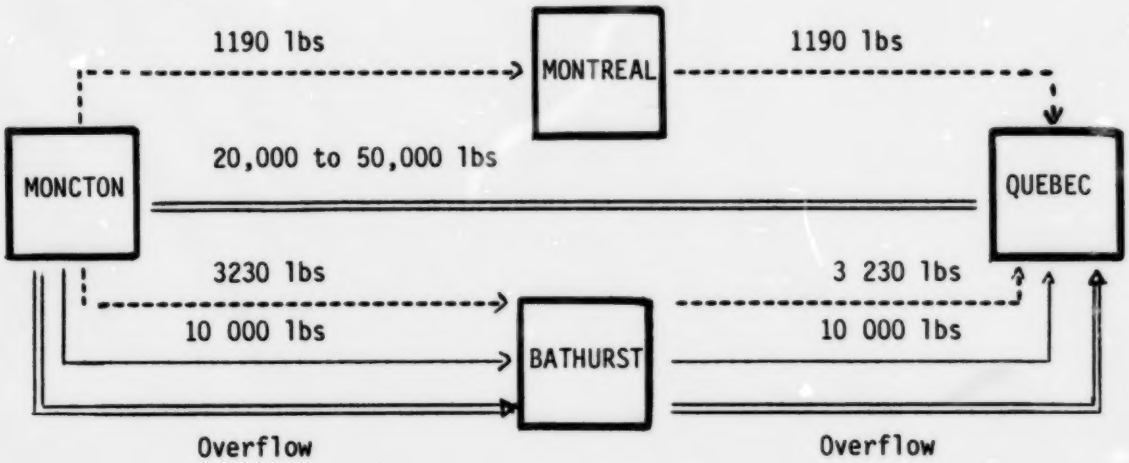
Legend : When $d_m = 0.8\ \bar{d}_m$, the freight follows ---------->
When $d_m = 1.0\ \bar{d}_m$, the freight follows ———————>
When $d_m = 1.2\ \bar{d}_m$, the freight follows ═══════>

Figure 4 : Again, NETPLAN determines the best routing of freight for varying demand levels. In this particular case, an alternate route through Edmonton is suggested for small quantities of excess freight between Toronto and Calgary.

Here we find that the normal route selected is the direct link between Toronto and Calgary, except when existing capacity is not sufficient for a relatively small portion of traffic (2230 lbs). This additional freight will therefore be routed through Edmonton, thereby increasing handling costs at this terminal instead of adding another trailer departure which would be much more expensive. It is also interesting to note that in this particular case, the rerouted surplus freight will still arrive at its destination on-time; i.e. there will be no increase in service penalty costs.

5.2 Demand Variations - Specific Market Demand

The preceding examples indicate that our model properly establishes the necessary trade-offs between freight transportation and handling costs, on the one hand, and service speed and reliability, on the other. When planning at the tactical level, motor carriers can determine which itineraries will be selected according to the general demand level expected. Furthermore, various analyses can also be performed on the level of demand to be expected for a specific market. For example, Figure 5 shows what happens when the demand level for a given market, in this case Moncton to Quebec city, is increased from its original level, i.e. 4420 lbs, up to 50,000 lbs.



Legend : When demand is 4 420 lbs, freight follows ----------→
When demand is 10 000 lbs, freight follows ——————→
When demand is 20 000 lbs or more, freight follows ⟹

Figure 5 : When demand for a specific market, e.g. Moncton to Quebec City, is expected to increase, NETPLAN can determine the appropriate routing of freight, and alternate routes for overflow, for varying demand levels.

When demand is set at its original level of 4 420 lbs the flow of traffic is split into two routes that go through consolidation terminals in Montreal and Bathurst. As the volume increases to 10 000 lbs per week, freight will be routed through Bathurst only. Finally, when the demand level increases to 20 000 lbs and more, a direct link between Moncton and Quebec City will be justified.

In this example, the number of departures of direct services between Moncton and Quebec City will increase with demand for that specific market. Furthermore, when demand slightly exceeds the transportation capacity between Moncton and Quebec City, the overflow will be routed through Bathurst, thereby determining an alternate route for that market.

5.3 Modifications to transportation services using rail

A motor carrier using rail services to move its trailers over long distances may be interested in evaluating the impact of a reduction in rail services. We have performed two analyses: the first one consists of eliminating all rail services leaving Toronto while the second one measures the impact of increasing the transit time, T_1, for all rail services in the network.

Table 2 shows the results obtained when performing the first analysis. First, we observe that total costs increase when the seven (7) rail services leaving Toronto are eliminated. This is due mainly to an increase in freight handling costs following the rerouting of traffic that used to move on rail services out of Toronto. By using more indirect itineraries, this traffic is taking more time to get to its final destination, thereby generating additional service penalty costs and savings in transportation costs that are due to increased consolidation of freight.

Performance Criteria	Original Solution	Modified solution
a) Weekly costs		
. Transportation	$ 454,144	$ 452,438
. Freight handling	64,575	68,746
. Capacity penalty	165	256
. Service penalty	52,229	53,063
TOTAL	$ 571,113	$ 574,503
b) Statistics		
. Frequencies used	1,094	1,102
. Rail services eliminated	--	7
. Rail departures eliminated	--	47
. Modified itineraries	--	66
. Amount of freight transferred	71,873	76,937

Table 2 : The results obtained when eliminating rail services leaving Toronto and the comparison with the original solution, show an increase in total costs due to additional freight handling (CNX data).

The second analysis calls for gradual increases in the transit time, T_1, for all rail services in the network. Results are shown in Table 3. We notice a decrease in the number of rail services used as the transit time increases along with an increase in the number of road services used. We can also observe a gradual increase in freight handling and service penalty costs. This is explained by the increased amount of freight being rerouted to road services that may require additional handling at intermediate terminals over long distances, when compared with previous movement by rail. This kind of analysis is particularly useful when the reliability of transit time for a given type of transportation service is questionable.

Performance Criteria	$T_1 = \overline{T_1}$	$T_1 = 1.2\overline{T_1}$ (Rail)	$T_1 = 1.4\overline{T_1}$ (Rail)	$T_1 = 1.6\overline{T_1}$ (Rail)
a) Weekly costs				
. Transportation	$ 454,144	$ 463,145	$ 473,828	$ 488,968
. Freight handling	64,575	64,918	70,921	74,439
. Capacity penalty	165	46	78	143
. Service penalty	52,229	56,083	68,226	74,253
TOTAL	$ 571,113	$ 584,192	$ 613,053	$ 637,803
b) Frequencies used				
. Rail services	403	372	345	261
. Road services	691	735	787	877
. All services	1,094	1,107	1,132	1,138
c) Amount of freight transferred (CWT)	71,873	72,769	77,555	83,152

Table 3 : The results obtained when varying the transit time, T_1, for all rail services indicate an increase in transportation cost, due to a shift towards more expensive but faster transportation modes (CNX data).

5.4 Modifications to the network configuration

In this section, we report on the use of our tactical planning model to evaluate the impact of adding a new breakbulk terminal in Toronto, based on a real decision made by CNX in 1983. This new facility was much more efficient than existing ones in the Toronto area: productivity was increased by 40% and turnaround time was significantly reduced for traffic being transferred in Toronto. This resulted in improved operating costs and service performance as shown in Table 4.

Our tactical planning model also measures the impact of such a network modification on the amount of freight handled in Toronto and consequently on the routing of freight through the modified network.

Additional analyses were performed on this data set in order to evaluate the sensitivity of the solution to various productivity improvement measures and their impact on the network balance between the number of trucks leaving and arriving at each terminal. Results are reported in Roy (1984).

Performance Criteria	Original Networks	With the new terminal
a) Weekly costs		
. Transportation	$ 454,144	$ 452,965
. Freight handling	64,575	62,447
. Capacity penalty	165	111
. Service penalty	52,229	40,352
TOTAL	$ 571,113	$ 555,875
b) Statistics		
. Freight transferred (CWT)		
- in Toronto	6,647	15,124
- elsewhere	65,226	55,730
. Frequencies used	1,094	1,095

Table 4 : Results obtained when adding a new breakbulk terminal in Toronto indicate the savings generated by such a decision (CNX data).

VI OTHER APPLICATIONS AND PERSPECTIVES

Our tactical planning approach has been adapted to other situations as well. For example, a PC version was developed recently (Roy and Delorme, 1989a) in order to assist Canada Post Corporation in its network reconfiguration study. The purpose was to study the impact of modifying the processing capacity and location of various postal facilities across Canada on overall network performance, in terms of processing costs, service speed and reliability, and mail routing. Our approach was also tested on rail data from the Canadian (Crainic, 1984) and French (Crainic and Nicole, 1986) national railways. We are presently undertaking research into the air cargo tactical planning area and strongly believe that a similar approach could also be used by shippers who manage large transportation networks.

Two conclusions emerge from all these case studies and analyses. On the one hand, the model captures well the operational and planning complexity inherent in a large transportation system and it may be tailored to fit the needs of particular organizations. Consequently, it offers realistic solutions which achieve the desired trade-offs between economic performance and service criteria.

Furthermore, scenario analyses, such as those presented in this paper concerning the evaluation of routing policies in response to varying demand, are an invaluable asset when preparing contingency plans in a changing economic and regulatory environment.

On the other hand, in order to achieve this performance, the model has a complex mathematical structure, where several parameters have to be specified by the user, while the solution method offers several mechanisms to control the optimization process and the various scenario analyses. Thus, a non-technically trained user may experience some difficulties in using the model.

To address this problem, we are developing a planning system which incorporates the load planning model (and corresponding solution method) presented in this paper. This system also features interactive-graphic capabilities (Crainic and Mondou, 1990) which allow the user to tailor the model to its particular problem, to define scenarios, to supervise the solution process, and to visually analyze and compare data and results. Thus, the manager's attention will be focused not on how to make the model work, but rather on how to use the available information and model capabilities to make the most appropriate decision.

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APPENDIX A

LOAD PLANNING MODEL FORMULATION

The following index sets are defined:

l : Denotes a specific transportation service that the company may offer.

j : Denotes a breakbulk terminal

m : Stands for a particular market.

k : Identifies a specific freight itinerary for market m.

The general form of the model can be stated mathematically as follows:

$$\underset{(F,X)}{\text{Minimize}} \quad \sum_{l} \omega_l(F) + \sum_{j} \beta_j(X) + \sum_{l} \gamma_l(F,X) + \sum_{m} \sum_{k} \Pi_k^m(F,X)$$

Subject to

(1) Demand constraints

$$\sum_{k} X_k^m = d^m \quad \text{for all } m$$

(2) Integer and continuous variables

$$X_k^m \quad 0 \quad \text{for all } m \text{ and } k$$

$$0 < F_l < E_l \quad \text{and } F_l \text{ integer for all } l$$

where the decision variables are

F_l : The frequency of service l; F is the vector of all F_l variables.

X_k^m : The volume of freight of market m routed through its k^{th} itinerary; X is the vector of all such variables

and

d^m : Demand for market m.

E_ℓ : An upper bound on the frequency of service ℓ.

The terms of the objective function are defined as follows:

C_ℓ^t : Unit transportation cost for service ℓ.

$\omega_\ell(F)$: Total transportation cost for service ℓ. Usually, this function is linear:

$$\omega_\ell(F) = C_\ell^t F_\ell$$

C_j^c : Unit freight consolidation cost at terminal j.

X_j^c : Total volume of freight handled at terminal j.

$\beta_j(X)$: Total consolidation cost at terminal j. The usual form of this function is:

$$\beta_j(X) = C_j^c X_j^c$$

$\gamma_\ell(F,X)$: Capacity penalty cost for the over-utilization of the total trailer capacity of service ℓ.

This is a non linear function written as

$$\gamma_\ell(F,X) = C_\ell^p \{\min (0, 0.9 - X_\ell/\alpha_\ell F_\ell)\}^2$$

where

C_ℓ^p : Unit capacity penalty cost, usually set equal to C_ℓ^t.

X_ℓ : Total volume of freight moved by service ℓ.

α_ℓ : Average capacity of vehicles assigned to service ℓ.

Finally

$\Pi_k^m(F,X)$: Service penalty cost for market m, incurred on its itinerary k, when the service performance standards for market m are not met.

This is a nonlinear function of the form:

$$\Pi_k^m(F,X) = C_m^s X_k^m \{\min (0, S_m - E(T_k^m) - n\sigma(T_k^m))\}^2$$

where

C_m^s : Unit service penalty cost for market m.

S_m : The required service standard for market m.

n : A positive number which depends on the required service reliability (it may be indexed by market).

T_k^m : The total transit time for freight moving on itinerary k of market m; $E(T_k^m)$ is the average transit time and $\sigma(T_k^m)$ its standard deviation.

The total transit time T_k^m usually depends on both the X and F variables and is computed as the sum of the total frequency delay at terminals (waiting for the service departure - nonlinear function derived form queuing theory), plus the total interterminal transportation time (linear function), plus the vehicle waiting time at terminal gates for unloading (nonlinear function derived form queuing models), plus the total freight handling time at each terminal (linear with the freight volume).